Radon - NOT the Silent Killer the EPA Wants You to Believe

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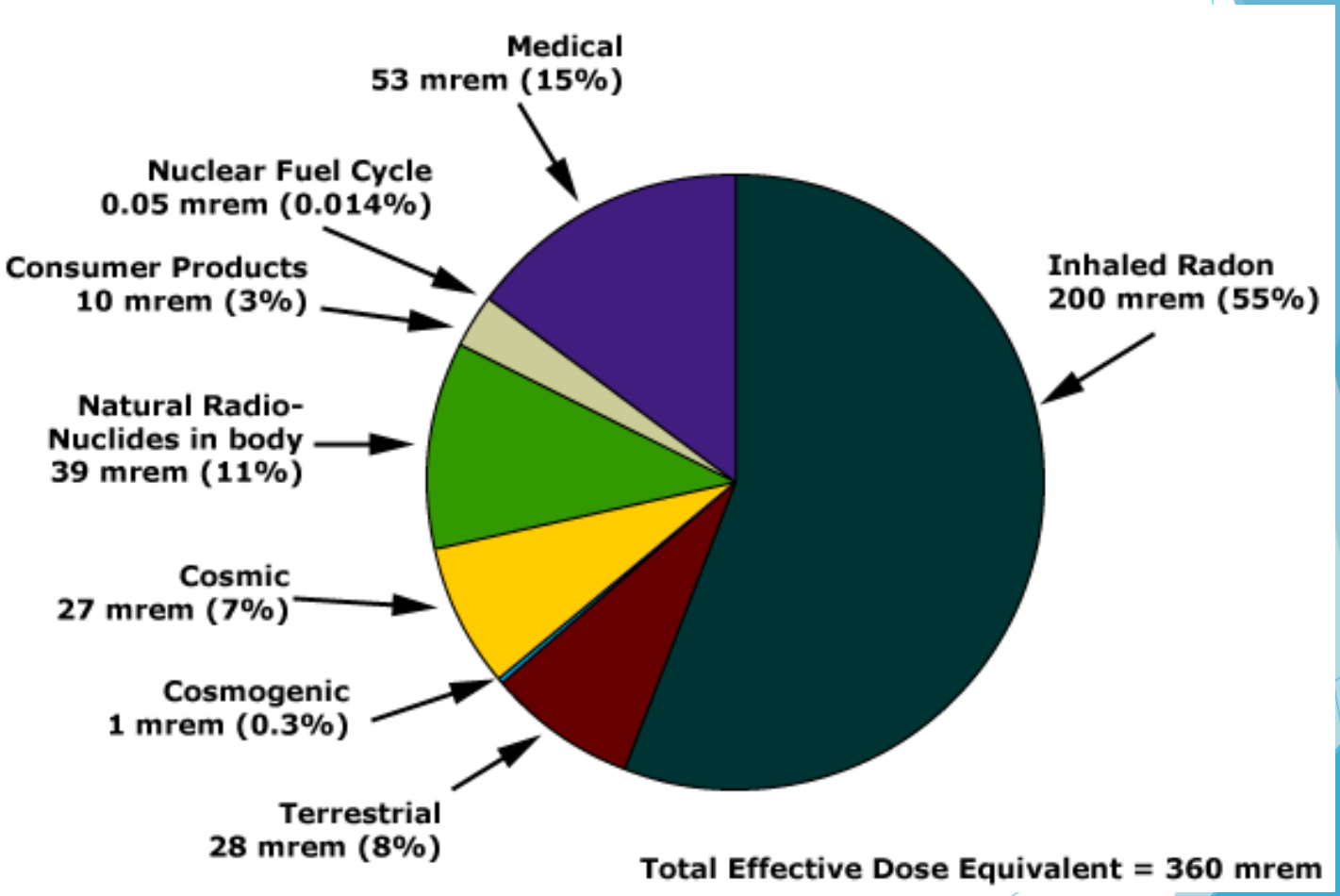
Radon Most Significant Contributor to Natural Background Radiation Dose

- Average U.S. dose from natural background radiation (cosmic, terrestrial, radon, and internal sources) generally taken to be ≈300 mrem/year[a]
- Radon contribution is ≈200 mrem/year[a,b,c]
  - Air we breathe contains radon gas and solid byproducts from radon decay that get attached to aerosol particles
  - While most radon exhaled when breathing, byproducts from radioactive decay remain in lungs to produce lung tissue radiation dose

Sources of Natural Background Radiation*



* Lawrence Berkeley National Laboratory, 2011 (https://www2.lbl.gov/abc/wallchart/chapters/appendix/appendixd.html)

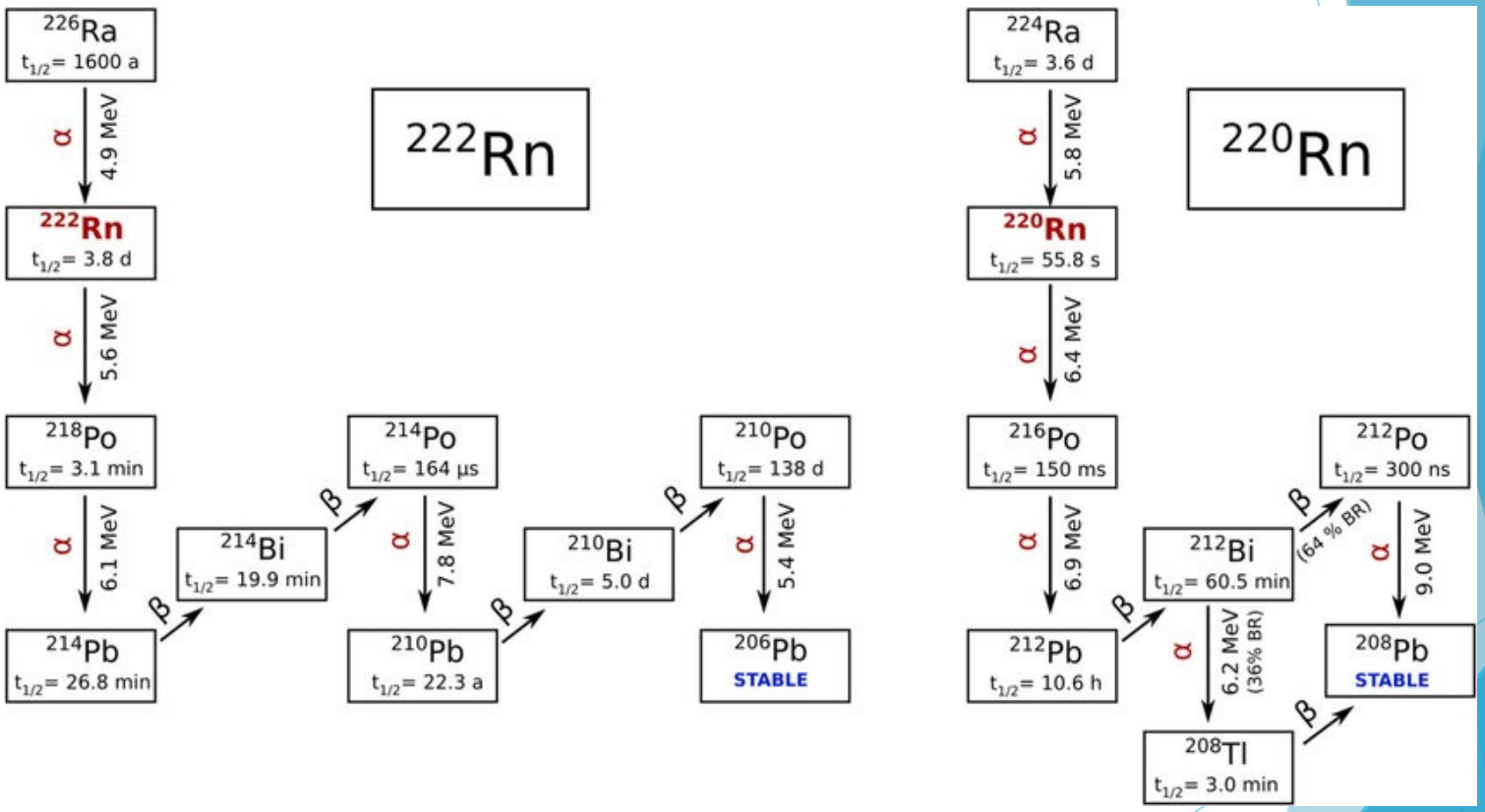
Source of Radon

- Radon is radioactive noble gas that enters atmosphere from radioactive decay of uranium-238 and thorium-232 in Earth's crust
  - Radon-222 (Rn-222), with half-life of 3.8 days, arises from radioactive decay of U-238
  - Radon-220 (Rn-220), with half-life of 55.8 seconds, arises from radioactive decay of Th-232
- Rn-222 and short-lived radioactive decay products most important contributors to human exposure from natural radiation sources

Source of Radon (cont.)

- Due to very short half-life, Rn-220 is lesser contributor to most human radon exposures
  - Timeframe for diffusion of short-lived Rn-220 in soils results in some decay to non-gaseous radioisotopes before reaching soil surface
  - Very short half-life results in little travel distance from origination site to immediate environment of human beings before decay to non-gaseous radioisotopes

Radon Decay Chains



Rn-222 Progeny Health Concern

- Rn-222 itself not huge health concern, since most inhaled radon exhaled before radioactive decay occurs
- Inhalation of Rn-222 short-lived solid progeny (Po-218, Pb-214, Bi-214, and Po-214) attached to aerosol particles become more significant health concern through absorption by lung tissue
- Most of inhaled aerosolized longer-lived Pb-210 excreted from body before radioactive decay occurs

Rn-222 Progeny Health Concern (cont.)

- Biological harm mostly from alpha particles emitted by solid Rn-222 progeny in lungs; some beta particles and gamma-rays also emitted
  - General agreement that alpha particles responsible for lung cancer seen in miners before mines were ventilated
- Almost all radon level measurements expressed as concentration of radon in picocuries per liter (pCi/L) of air or in becquerels per cubic meter (Bq/m^3) of air
  - 1 pCi/L = 37 Bq/m^3

EPA Assault on Home Radon[a]

- U.S. Environmental Protection Agency declared radon to be “silent killer”
  - Claims no known safe level of radon exposure
  - Alleges radon second leading cause of lung cancer behind smoking
  - Estimates 21,000 radon-related lung cancer deaths per year in U.S., with 2,900 being non-smokers[b,c]
  - Established action level for remediation of indoor radon
- National Health Advisory on Radon issued January 2005[d] recommending indoor radon remediation action level of 4 pCi/L

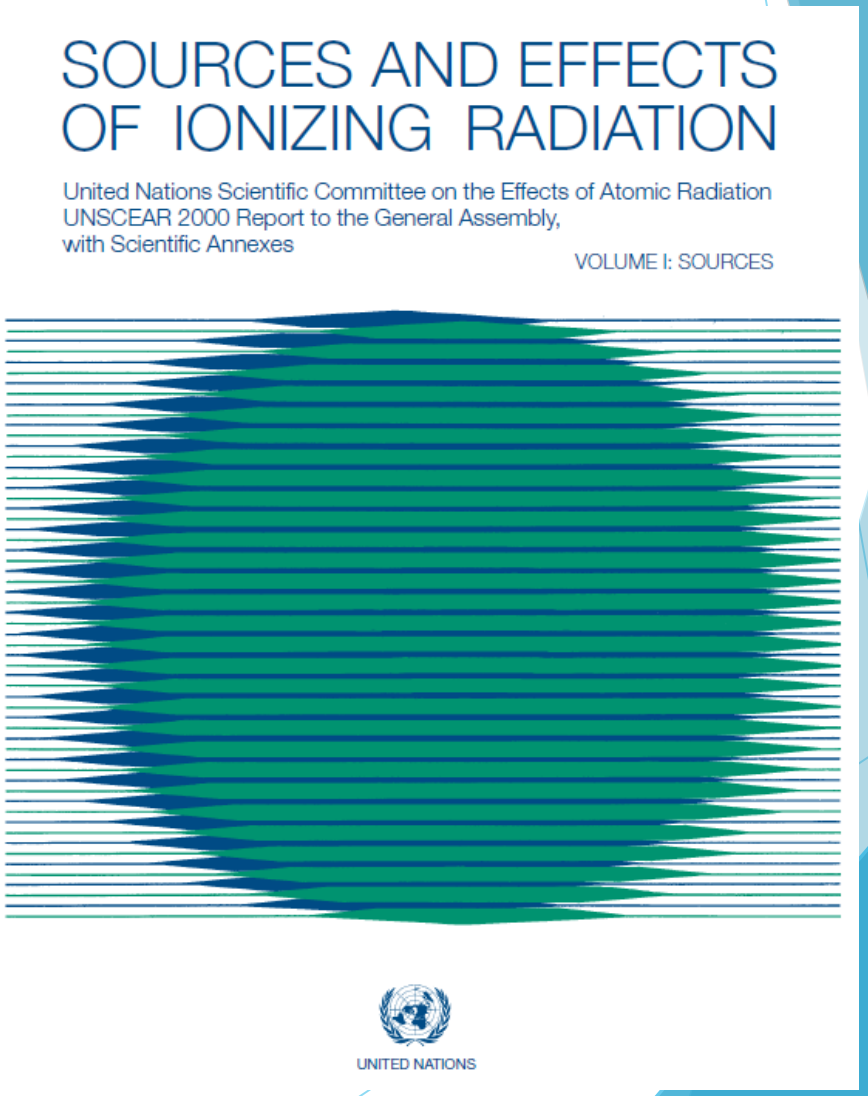
EPA Indoor Radon Remediation Action Level

- U.S. EPA assumes average annual inhaled radon dose of 200 mrem correlates with radon concentration of 1 pCi/L[a,b]
- EPA indoor radon remediation action level of 4 pCi/L then relates to average annual inhaled radon dose of 800 mrem
  - 800 mrem annual dose corresponds to average chronic radon dose-rate of 0.091 mrem/hour --- factor of roughly 30 below high-LET, high-dose-rate threshold of 3 mrem/hr (threshold for potential adverse health effects when biological adaptive protection taken into account); indoor remediation for average chronic radon dose-rate less than 3 mrem/hr unwarranted

a. Assessment of Variations in Radiation Exposure in the United States, United States Environmental Protection Agency, July 15, 2005, page 12
b. NCRP Report 93, *Ionizing Radiation Exposure of the Population of the United States*, 1987

UNSCEAR 2000 Report

One of most comprehensive studies on effects of ionizing radiation – provides detailed assessment of both indoor and outdoor global radon doses


SOURCES AND EFFECTS OF IONIZING RADIATION
United Nations Scientific Committee on the Effects of Atomic Radiation
UNSCEAR 2000 Report to the General Assembly,
with Scientific Annexes
VOLUME I: SOURCES
UNITED NATIONS

Both Rn-222 and Rn-220 Doses Evaluated in UNSCEAR Report

- Half-lives of Rn-222 and Rn-220 isotopes as well as various decay radioisotopes important for determining relative contributions to bronchial dose
- Half-life differences of radioisotopes from Rn-222 and Rn-220 decay produce very different atmospheric distributions of potentially aerosolized decay products

UNSCEAR 2000 Report Annual Radon Dose Calculations

- Basis for UNSCEAR annual dose calculations[a]
  - Absorbed dose coefficient of 9 nGy(Bq hour m^{-3})$^{-1}$ [nanoGray per Becquerel hour per cubic meter] for basal cells of bronchial epithelium derived from epidemiological studies and physical dosimetry for average indoor radon conditions
  - Applying apportioned tissue weighting factor of 0.08 for bronchial cells and quality factor of 20 for alpha particle radiation produces equivalent dose coefficient of about 15 nSv(Bq hour m^{-3})$^{-1}$

Gray – absorbed dose unit, Sievert – equivalent dose unit
Becquerel – 1 disintegration per second

UNSCEAR 2000 Report
Radon Dose Calculations (cont.)

- Basis for UNSCEAR dose calculations (cont.)
  - Population-weighted global average Rn-222 concentrations of 40 Bq/m^3 (1.08 pCi/L) indoors[a] and 10 Bq/m^3 (0.27 pCi/L) outdoors[a]
  - Equilibrium factors of 0.4 for indoor radon[b] and 0.6 for outdoor radon[b] (factors defined to permit radon exposure estimates in terms of potential alpha particle energy concentration from measurements of radon gas concentration)
  - Occupancy factors[c] of 0.8 indoor (≈7000 hours per year) and 0.2 outdoor (≈1760 hours per year)

UNSCEAR Radon Doses

- Indoor and outdoor Rn-222 concentrations result in global average annual equivalent lung doses[a] of about 1.7 mSv and 0.16 mSv, respectively
  - Rn-220 total annual lung dose[b] ≈0.09 mSv
- Total global average annual equivalent lung dose from both Rn-222 and Rn-220 radioactive decay is then ≈2 mSv (200 mrem)

EPA Radon Dose Calculations

- According to EPA, average U.S. indoor and outdoor radon concentrations are ≈1.3 pCi/L (48 Bq/m^3) and ≈0.4 pCi/L (14.8 Bq/m^3), respectively, based on EPA 1991 national residential radon survey[a,b,c]
- Using UNSCEAR radon annual lung dose calculations, resulting U.S. average indoor and outdoor annual equivalent lung doses would then be ≈2.0 mSv (200 mrem) and ≈0.24 mSv (24 mrem), respectively
- EPA assumption correlating 200 mrem dose with radon concentration of 1 pCi/L clearly in error

UNSCEAR/EPA Radon Concentration/Dose Summary

	UNSCEAR	EPA
Avg. Indoor Rn-222 Concentration	1.08 pCi/L[a]	1.3 pCi/L[b]
Avg. Outdoor Rn-222 Concentration	0.27 pCi/L[a]	0.4 pCi/L[b]
Avg. Annual Indoor Lung Dose	1.7 mSv	2.0 mSv[c]
Avg. Annual Outdoor Lung Dose	0.16 mSv	0.24 mSv[c]

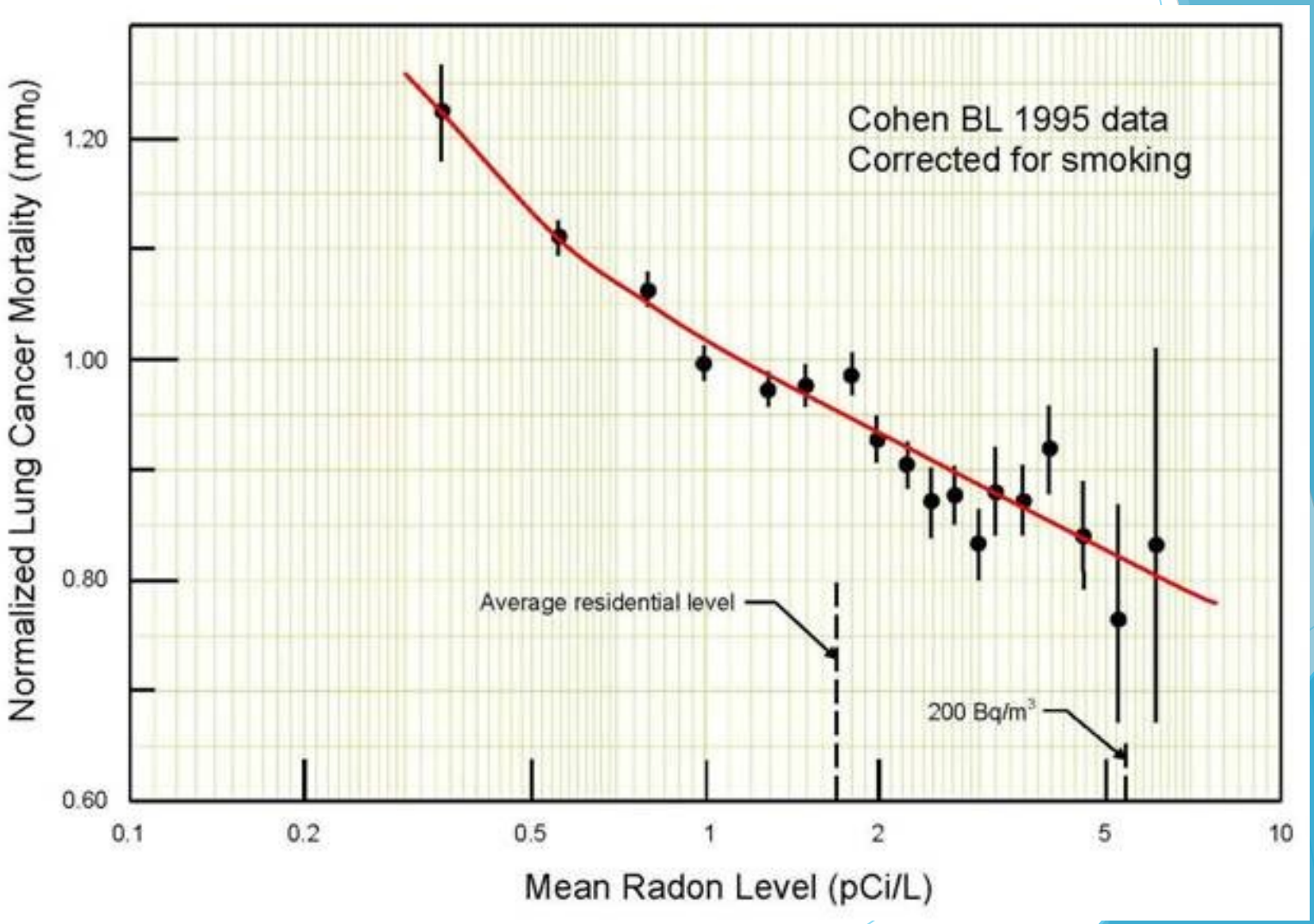
a – Population-weighted global average concentration from UNSCEAR 2000
Report
b – U.S. average concentration from 1992 EPA national residential radon
survey (updated 2023)
c – Calculated using UNSCEAR 2000 dose/concentration equilibrium factor,
occupancy factor, and equivalent dose coefficient of 15 nSv(Bq

Calculation of U.S. Average Indoor Radon Concentration

- Combining generally accepted average U.S. annual radon dose of 200 mrem* (2 mSv) with UNSCEAR indoor occupancy factor of 0.8,[a] results in average U.S. annual indoor radon lung dose of 160 mrem (1.6 mSv)
- UNSCEAR average annual indoor lung dose of 1.6 mSv then corresponds to average indoor radon concentration of 38 Bq m^{-3} or approximately 1.03 pCi/L, which is close to UNSCEAR average indoor Rn-222 concentration

* Lawrence Berkeley National Laboratory, 2011

Bernie Cohen Indoor Radon Study



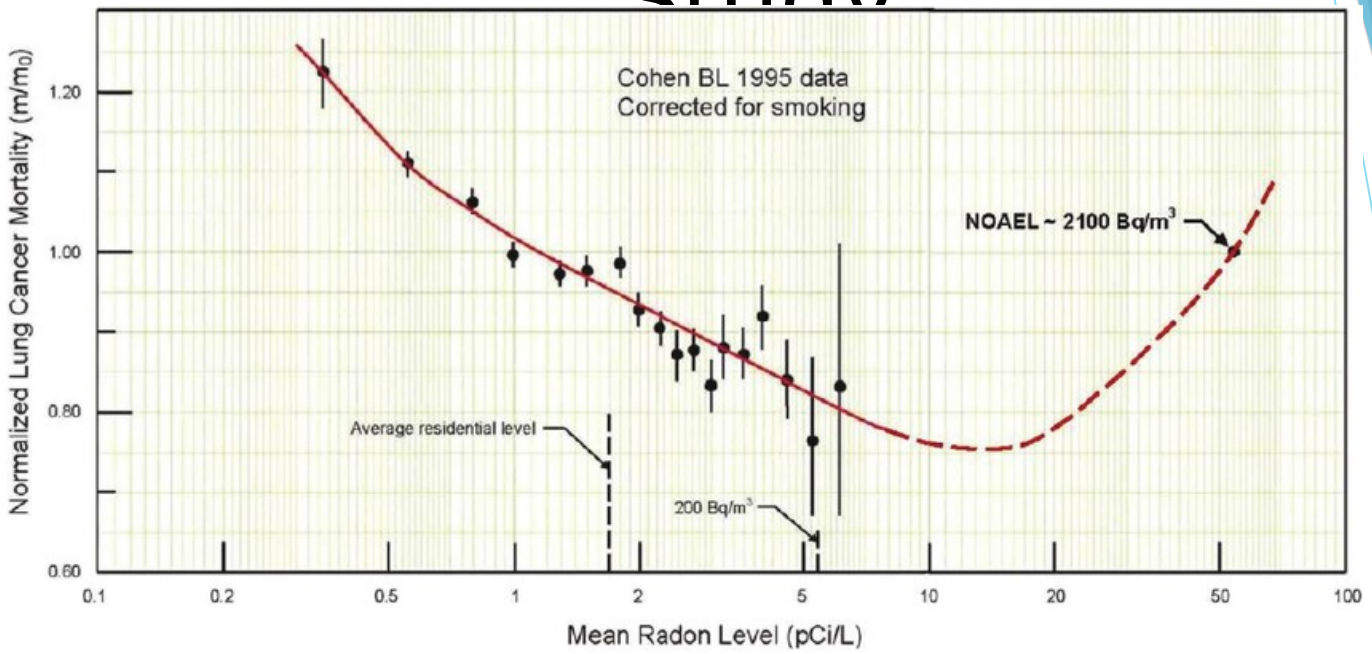
Bernie Cohen Indoor Radon Study (cont.)

- Cohen five-year investigation of radon-induced lung cancer in early 1990s
  - Covered 1,601 counties, comprising ≈90 percent of U.S. population
  - Consisted of radon data from EPA and state agencies, and 272,000 measurements by U. of Pittsburgh researchers
- Study intended to measure how quickly lung cancer rates increased with higher home radon levels
  - Found cancer rate decreased significantly with increasing levels of radon

Bernie Cohen Indoor Radon Study (cont.)

- Most important results from Cohen radon study
  - Lung cancer mortality increased with decreasing radon concentration below 1 pCi/L and decreased with increasing radon concentration between 1 pCi/L and 6 pCi/L
  - U.S. average indoor radon concentration of 1.7 pCi/L
- Average indoor annual equivalent dose associated with concentration of 1.7 pCi/L is 2.6 mSv (260 mrem)
- Numerous scientists tried unsuccessfully to refute study
  - Dozens of studies since have confirmed radon's protective (hormetic) effect at low exposure levels

Extrapolation of Indoor Radon Study



NOAEL – no observed adverse effect level

- Extrapolation of Cohen study data predicts decreased lung cancer mortality for indoor radon concentrations between 1 pCi/L and ≈56 pCi/L (2100 Bq/m^3)[a]

Indoor Radon Dose Summary

	UNSCEAR	EPA	LBNL[a]	Cohen
Average Indoor Radon Concentration	1.08 pCi/L	1.3 pCi/L	1.03 pCi/L	1.7 pCi/L
Average Annual Indoor Lung Dose[b]	1.7 mSv	2.0 mSv	1.6 mSv	2.6 mSv

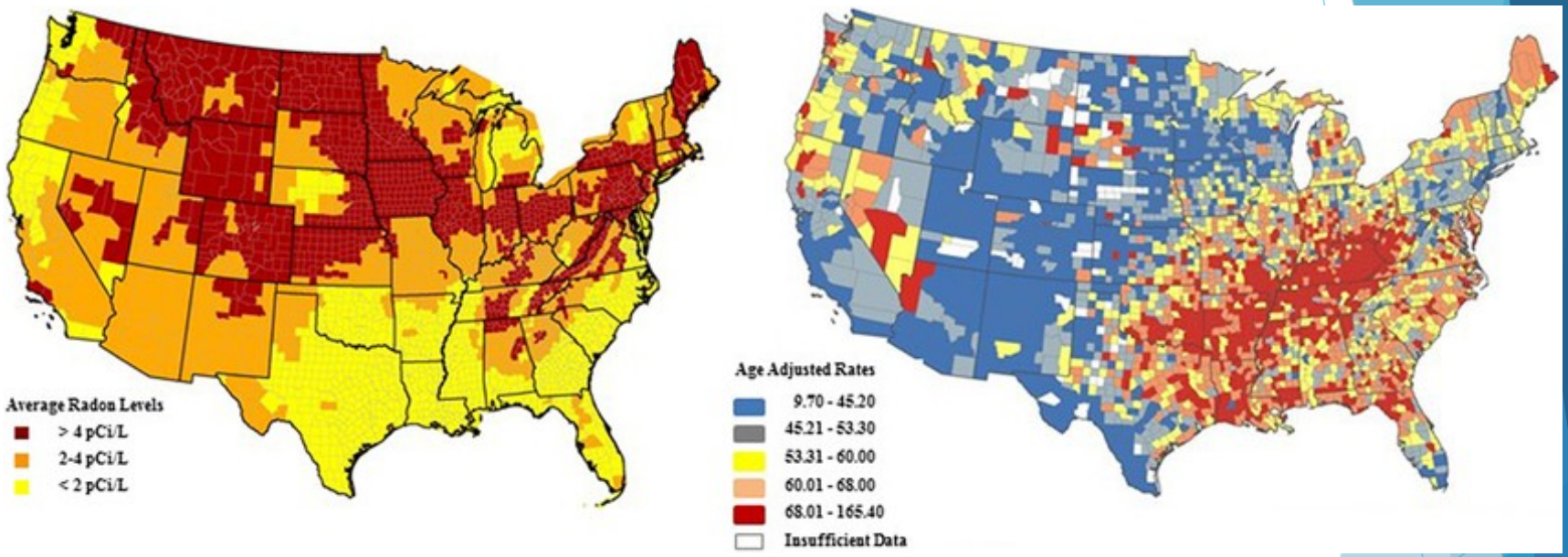
a - Lawrence Berkeley National Laboratory

b – Equivalent dose calculated using UNSCEAR 2000 dose coefficient of 15 nSv(Bq hr m^{-3})$^{-1}$

Flawed EPA Indoor Radon Remediation Action Level

- EPA assumption of correlation between radon concentration of 1 pCi/L and 200 mrem lung dose incorrect
- Furthermore, indoor radon remediation action level of 4 pCi/L corresponds to maximum radon lung dose of ≈612 mrem, well below EPA assumed level for potential harm of 800 mrem
- 4 pCi/L radon concentration well within hormetic region of Cohen indoor radon study, which shows increased health benefit of indoor radon concentrations between 1 pCi/L and 6 pCi/L

Radon Concentration vs Lung Cancer Mortality Rate



Left: Predicted average indoor radon levels (EPA Map of Radon Zones, provided with permission of EPA Radiation Protection Division).
Right: 2000 to 2009 lung cancer mortality rates per 100,000 by county, corrected for smoking (Static Maps, National Community Mapping Institute).

Data Challenging Legitimacy of EPA Home Radon Remediation Action Level

High background radon radiation areas of world showing no adverse health effects

- Kerala, India
- Guarapari, Brazil
- Ramsar, Iran

High Background Radiation Areas Around the World

Parts of Kerala, India have natural background radiation levels up to 76 mSv/year due to monazite in soil

- No significant correlation between cumulative radiation exposure and incidence of cancer or leukemia
- No excess birth defects

High Background Radiation Areas Around the World (cont.)

Tourists and residents cover themselves with thorium-rich beach sand

High Background Radiation Areas Around the World (cont.)

Most radioactive place in the world - Ramsar, Iran
(due to Radium-226)
Background radiation = 100 – 260 mSv / year

No epidemiological evidence of adverse affects

Lymphocytes from residents demonstrate fewer induced chromosome aberrations

City's 50 sulfurous hot springs contain high levels of radium-226

Final Note on Home Radon Levels

- Studies of uranium miners exposed to elevated concentrations of radon and daughter progeny in western U.S. established causal relationship between very high radon and radon daughter exposures and onset of lung cancer[1,3]
- Exposure levels were two to three orders of magnitude higher than those found in typical indoor environments[2,3]
- Cohen indoor radon study supports conclusion that home radon not a health hazard

Radon Health Spa Controversy[1]

- Bathing in radon-rich waters for enhancing human health traces back to medieval times
- Radon framed negatively in current public health discourse regarding indoor exposure, yet positively in central European radon health spa treatment contexts
- Legal regulatory frameworks govern radon spa designation and/or identification in Austria, Czech Republic, Germany, Hungary, Poland, and Slovakia
  - Established minimum thresholds distinguish medicinal from non-medicinal bathing waters based on radon concentrations
  - Medicinal thresholds range from 74 Bq/L (2000 pCi/L) in Poland to 1500 Bq/L (40,545 pCi/L) in Czech Republic

Radon Health Spa Controversy (cont.)

- Radon protection regulations in Austria, Czech Republic, Germany, Hungary, Poland, and Slovakia specify annual average workplace and residence concentration of 300 Bq/m^3 (8.1 pCi/L) in accordance with European Union Basic Safety Standards[1]
- Monitoring required to determine average workplace concentration and need for radon remediation measures

Revisiting EPA Radon Assault (cont.)

- Claim of no known "safe level" of radon exposure
  - Premise of no safe level of radiation based on flawed Linear No-Threshold dose-response model
  - Refuted by Cohen indoor radon study and lack of increased lung cancer mortality in worldwide high background radon radiation areas
  - Observed lower lung cancer risk in high background radiation areas[a,b,c]

Revisiting EPA Radon Assault

- Assertion of radon being second leading cause of lung cancer
  - Unsupportable supposition lacking identifiable marker to distinguish alleged radon-induced lung cancer from other potential environmental causes
  - Don’t know what causes each case of lung cancer (American Cancer Society)

Revisiting EPA Radon Assault (cont.)

- Established action level for indoor radon remediation –
  - No scientific basis for such action; counterproductive and harmful based on Cohen indoor radon study
- Claim of 21,000 U.S. radon-related lung cancers per year
  - Flawed LNT dose-response model used for predicting lung cancer morbidity/mortality; actual lung cancer deaths don't correlate with increased indoor radon concentrations
  - Hormetic relative risk model (Cohen indoor radon study) shows decreasing lung cancer incidence for indoor radon concentrations above EPA remediation action level; consistent with actual lung cancer data*

* Scott, BR., Residential Radon Appears to Prevent Lung Cancer, Dose Response 2011; 9(4): 444-464

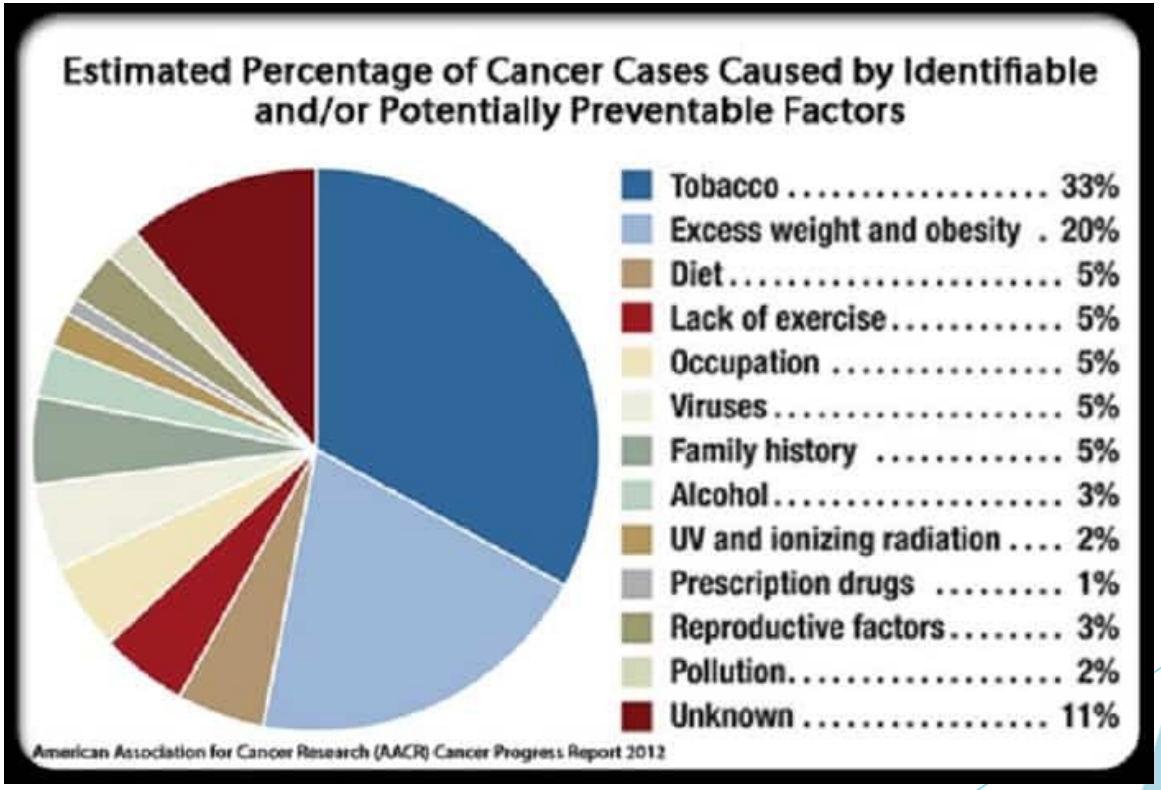
Radon Exposure in a Nutshell

- Radon exposure is chronic ionizing radiation exposure
- Chronic low-dose radiation exposures do not inhibit ability of body's adaptive protection mechanisms to repair radiation-induced cell damage (otherwise, we would not be here)
- Exposure to radon (indoor and outdoor) does not result in adverse health effects

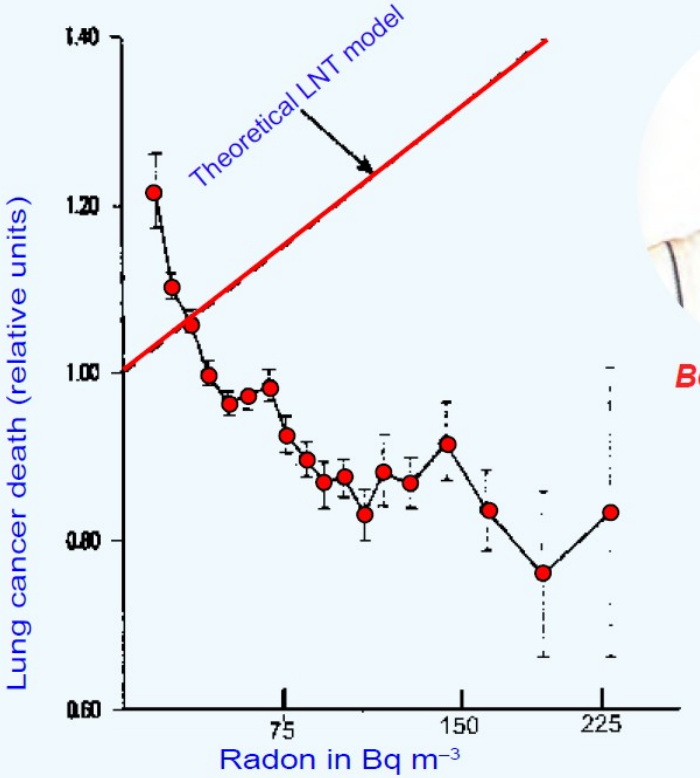
Supplemental Slides

Revisiting EPA Radon Assault

Radiation an extremely weak carcinogen


Estimated Percentage of Cancer Cases Caused by Identifiable and/or Potentially Preventable Factors
Tobacco 33%
Excess weight and obesity . 20%
Diet 5%
Lack of exercise 5%
Occupation 5%
Viruses 5%
Family history 5%
Alcohol 3%
UV and ionizing radiation 2%
Prescription drugs 1%
Reproductive factors 3%
Pollution 2%
Unknown 11%
American Association for Cancer Research (AACR) Cancer Progress Report 2012

Cohen Indoor Radon Study



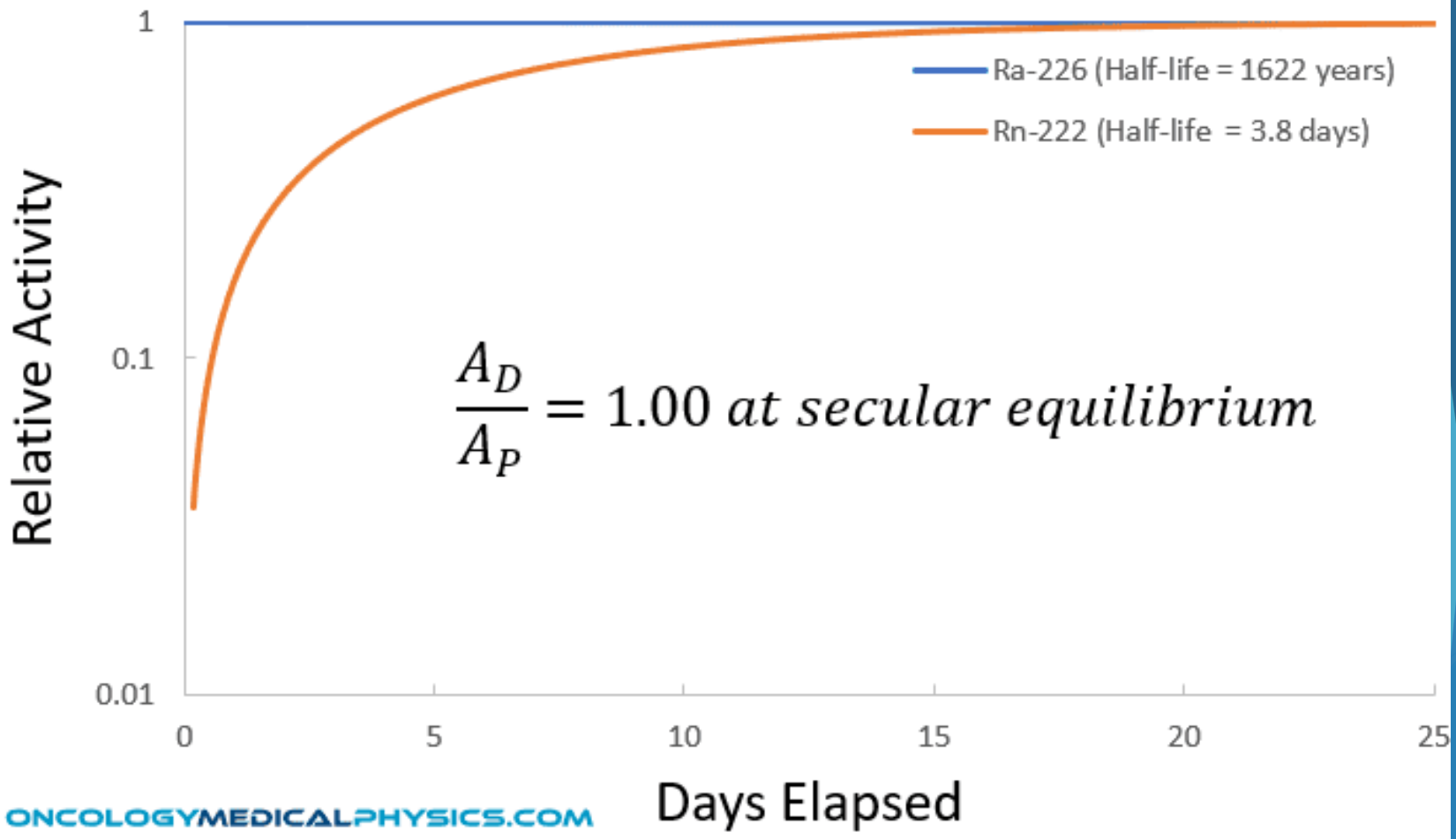
Bernhard Cohen

(1924 – 2012)

*The figure shows the main results of Bernhard L. Cohens investigations from 1995 and 2000. The main data are published in Health Physics **68 (2)**, 157 – 174 (1995).*
The data points from counties with almost the same radon level have been grouped together.

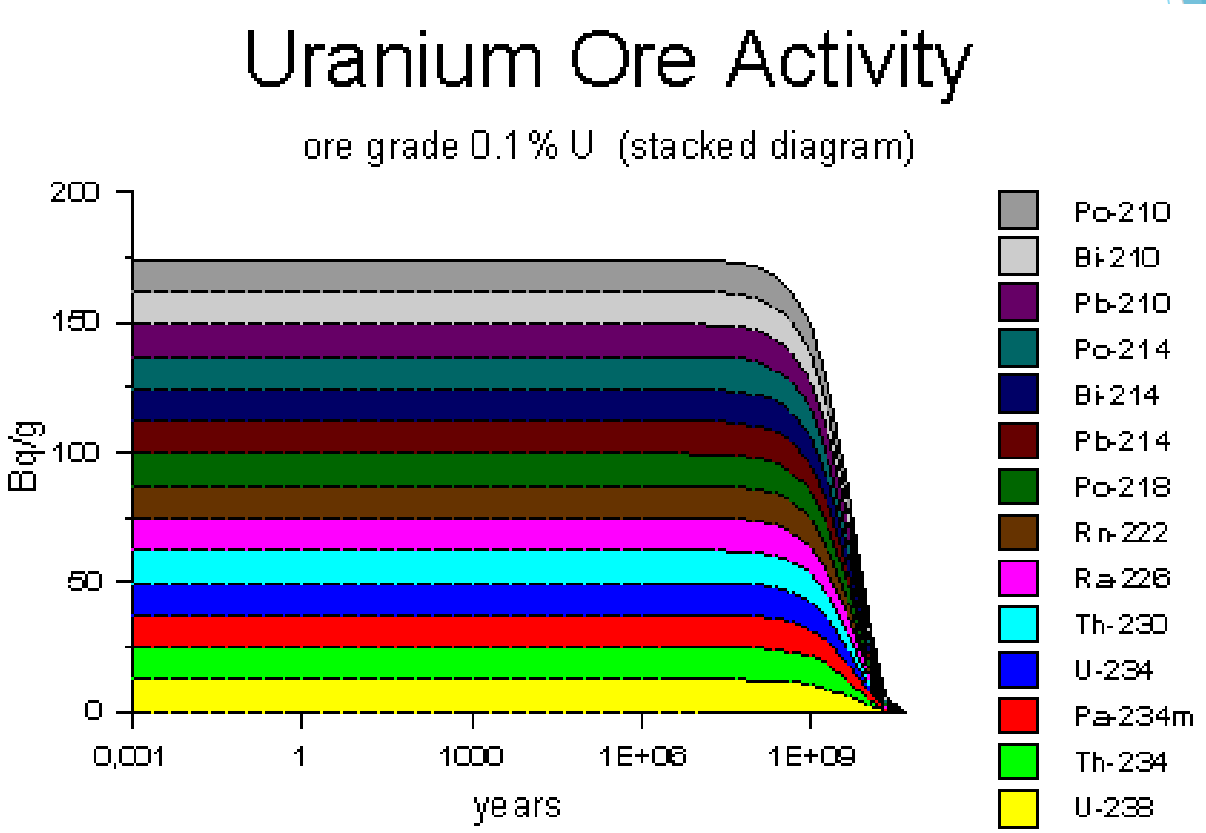
The data from 2000 include more recent cancer data. Furthermore, data for counties in Florida and California have been deleted because deaths there are frequently due to retirees who received their radon doses elsewhere. The results are however, not changed but are more or less equal to those presented above.

Secular Equilibrium in Ra-226 and Rn-222



A_D is activity of daughter radionuclide (Rn-222)
A_P is activity of parent radionuclide (Ra-226)

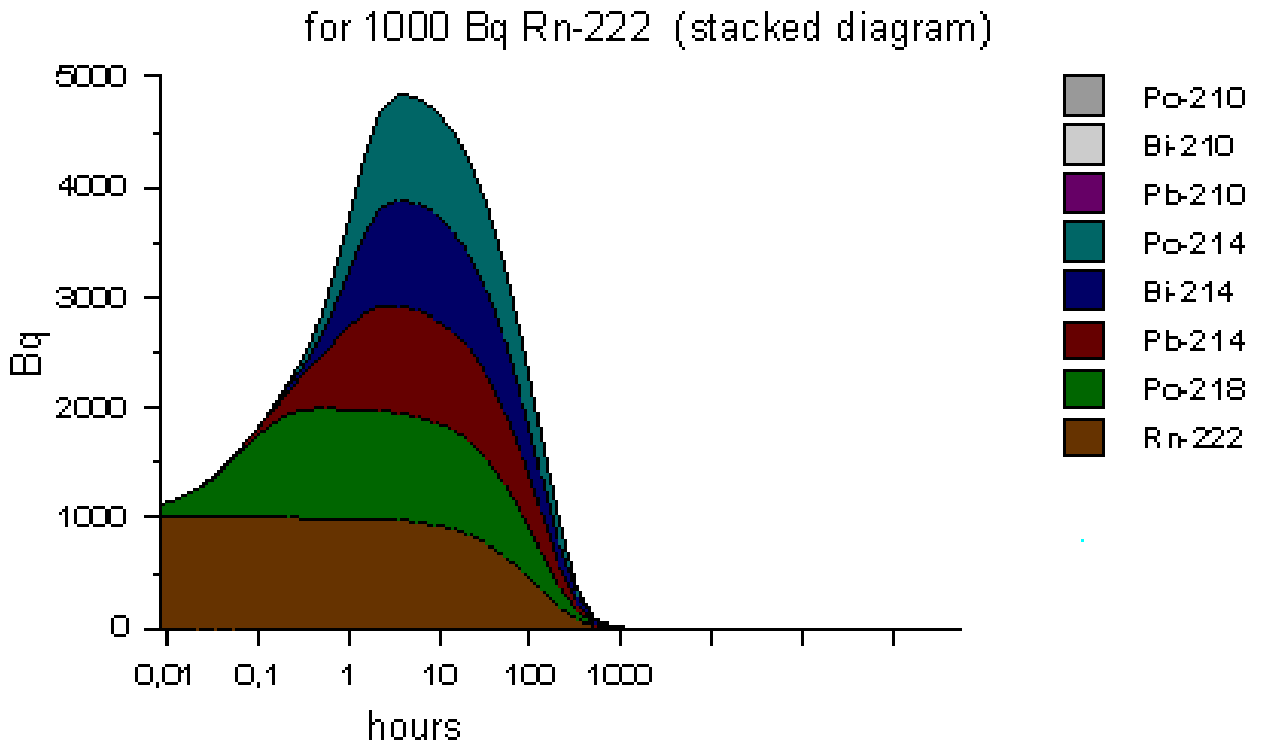
Source of Rn-222



U-238 progeny in <u>secular equilibrium</u> with U-238

- Equal production rate and decay rate for each daughter isotope
- Daughter activity governed by U-238 activity

Rn-222 and Progeny



Rn-222 progeny in <u>transient equilibrium</u> with Rn-222

- Daughter's activity becomes proportional to parent's activity, typically after four half-lives of daughter radioisotope
- Ratio of parent/daughter activities remains relatively constant
- Pb-210 (and progeny) not shown due to relatively rapid bodily excretion rate compared to radioactive decay rate (Pb-210 radiological half-life of 22.3 years, biological half-life in lung tissue typically 30–45 days)